elecnor deimos

6th International Conference on Astrodynamics Tools and Techniques

ICATT6, Darmstadt, 14-17 March 2016

NEO Threat Mitigation Software Suite

Juan L. Cano, Javier Martín, Gabriele Bellei

Presenter: Mariano Sánchez

NEOShield

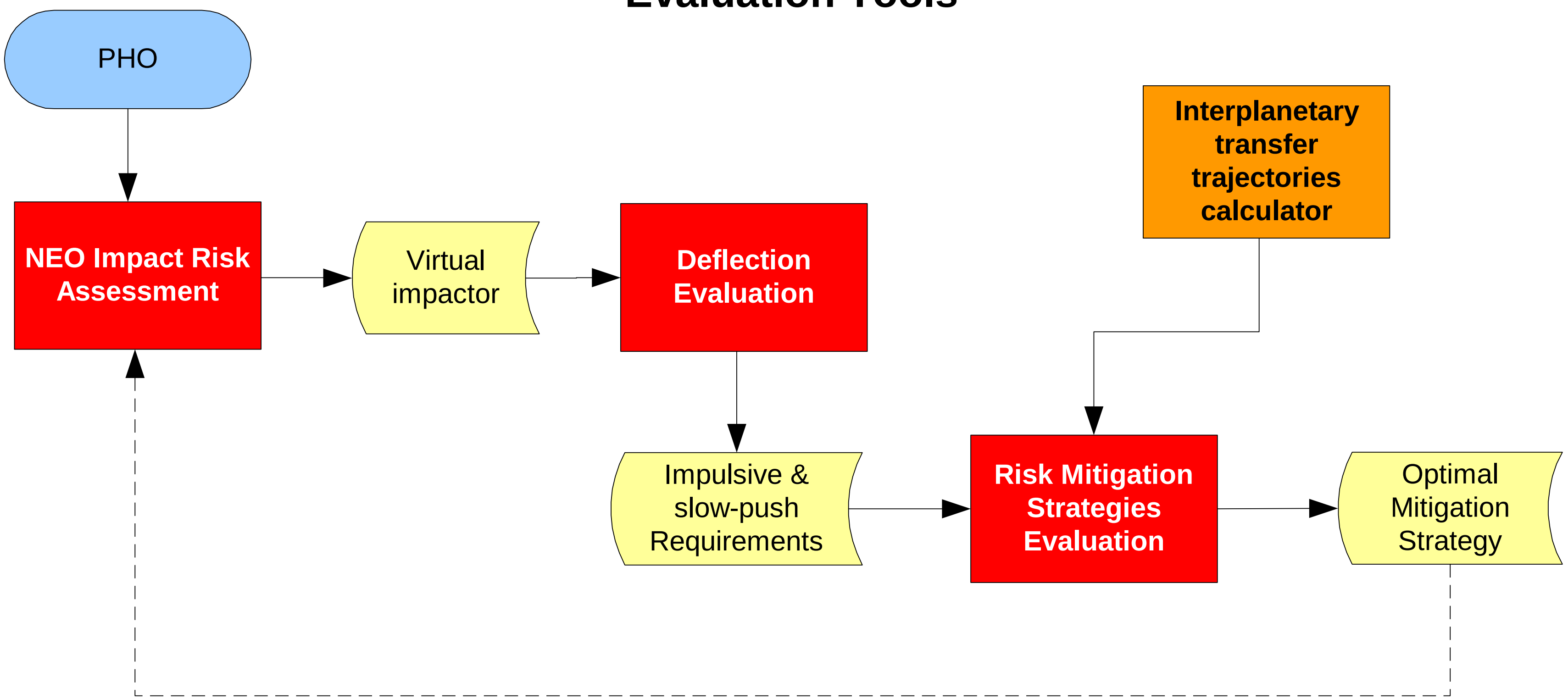
SEVENTH FRAMEWORK PROGRAMME

Context

- DEIMOS Space has participated in **NEO Mitigation activities since 2002** with the proposal to ESA to carry out the Don Quijote Phase 0 study in collaboration with University of Pisa and Astrium
- Studies followed on in 2006-2007 with the **Don Quijote** Phase A studies also for ESA
- Large degree of involvement in SSA-NEO since its inception
- In particular leadership in the **SSA-SN-VII** study for ESA
- Elecnor Deimos is one of the partners of the EC-FP7 **NEOShield** study and H2020 **NEOShield-2**
- Main roles of Deimos in NEOShield:
  - Leader of WP6 on GNC for the Kinetic Impactor concept
  - Partner in WP8 on a Phase A for a Kinetic Impactor mission
  - Partner in WP9 for the **development of a suite of S/W tools for NEO threat mitigation**

Software Suite Context

Risk and Deflection Evaluation Tools



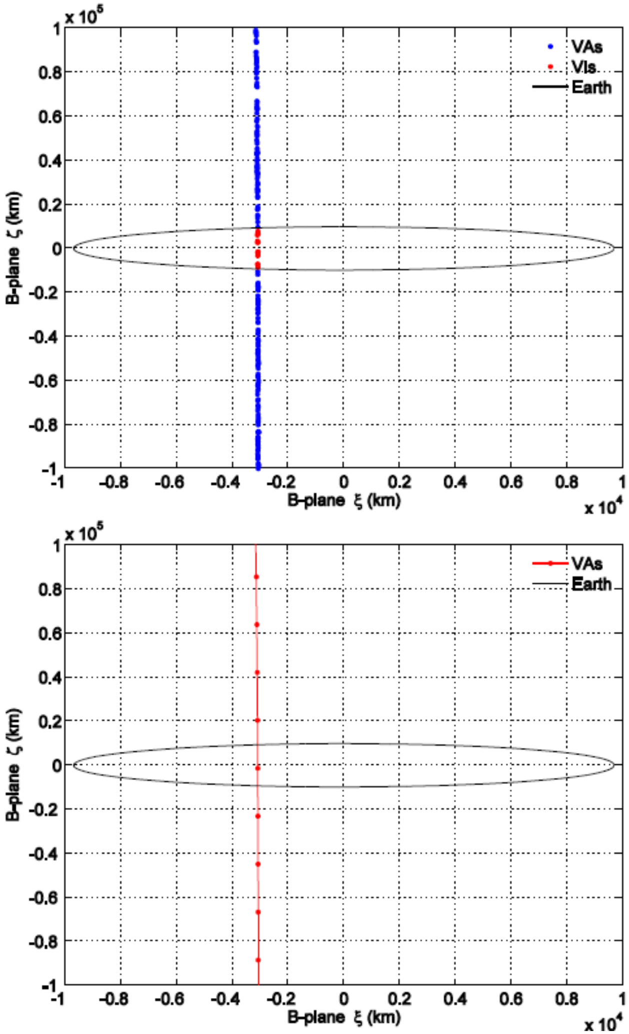
NIRAT Tool (1)

- Minor body propagator that finds close approaches to Earth of selected NEO
  - Considers the uncertainty in the initial state, generating a cloud of virtual asteroids with several methods
  - It provides virtual impactor information for later analysis with NEODET
- Provides a fast but precise assessment of the probability of impact of a particular NEO, from the source data provided by SENTRY/NEODyS

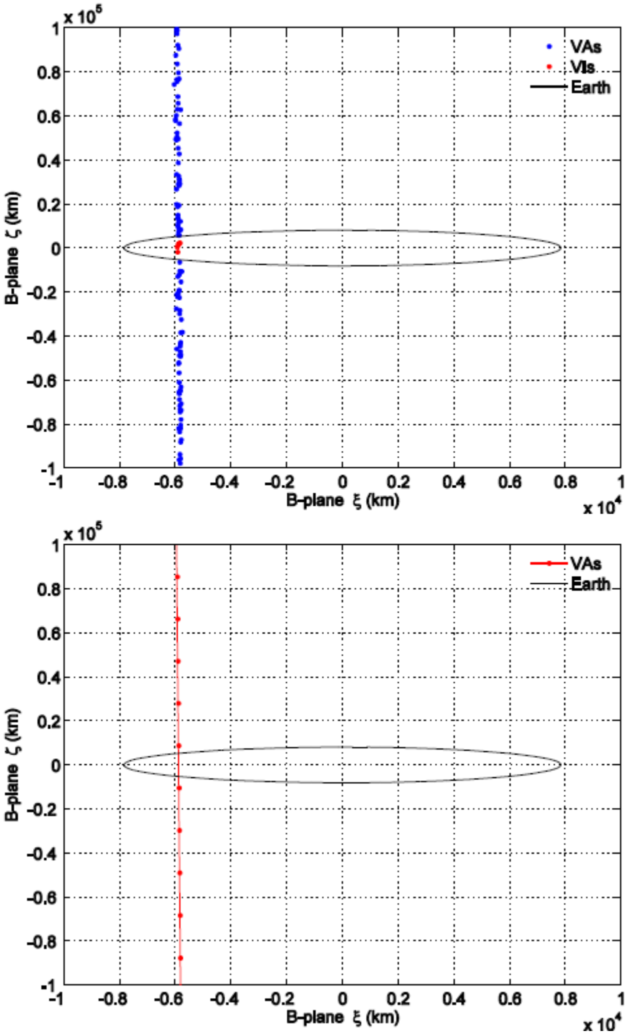
NIRAT Tool (2)

- The tool generates a cloud of virtual asteroids (VAs) by sampling the initial state uncertainty distribution.
  - NIRAT assumes a 6-normal uncertainty in the asteroid state
  - Each VA is propagated and any close approaches are recorded in the output file for post-processing.
  - A single propagation mode exists for test purposes.
- Methods for VAs generation:
  - Monte Carlo
  - Line of variations
  - Elliptical sampling
- The main output is a list of close encounters for each VA
  - B-plane plots
  - Keyhole analysis
  - Impact corridors on Earth

NIRAT Tool (3) / Typical Results

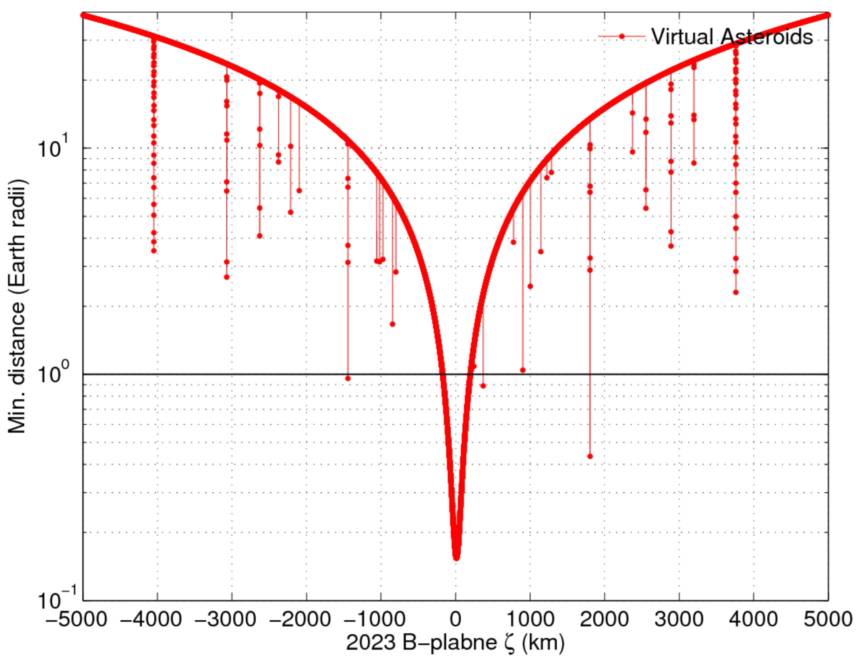


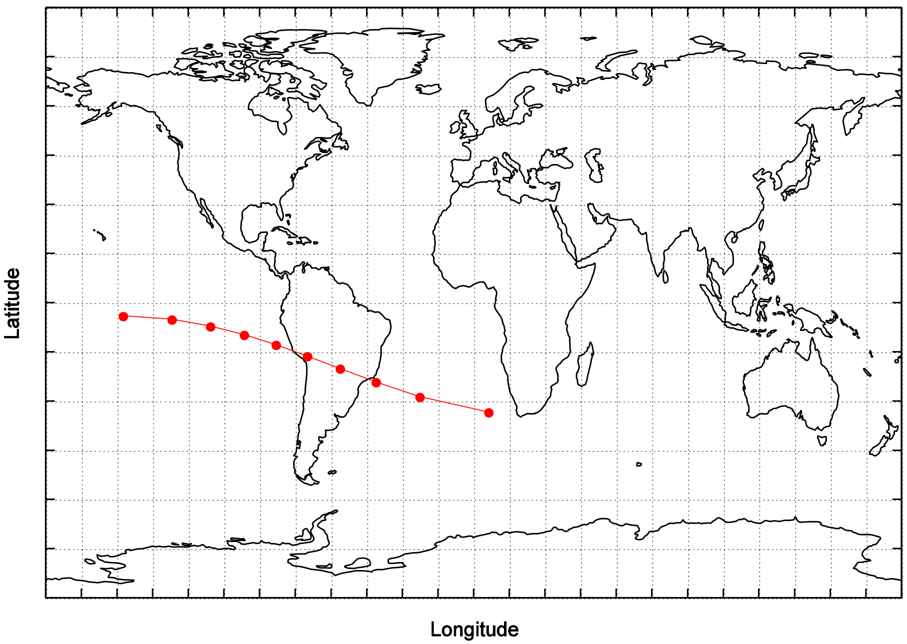
Monte Carlo (top) and Line of Variations (bottom) comparison on 2040 b-plane for asteroid 2011 AG5



Monte Carlo (top) and Line of Variations (bottom) comparison on 2048 b-plane for asteroid 2007 VK 184

NIRAT Tool (4) / Typical Results





Keyhole plot for 2011 AG5 2023 encounter with propagations up to 2060 (several encounters visible)

Approximate impact corridor of the 2011 AG5 VIs for the 2040 encounter (LoV)

NOTE: Provided figures correspond to calculations performed before 2011 AG5 ephemerides were improved to a no-risk level

NEODET Tool (1)

- Propagator that takes a virtual impactor and attempts to deflect its course over a range of dates by optimisation
  - Also serves to evaluate the effect of a proposed deflection
  - As the second tool in the suite, input data for NEODET will usually come from NIRAT, with the same propagation settings
  - Impulsive methods and slow push methods are both considered
- Includes a specialized analytic propagator (Bombardelli-Baù) for slow-push problems that avoids numerical propagation
  - Valid only for cases with no intermediate flybys

Initial VI state
Date range
Operation mode
Propagation data

NEODET

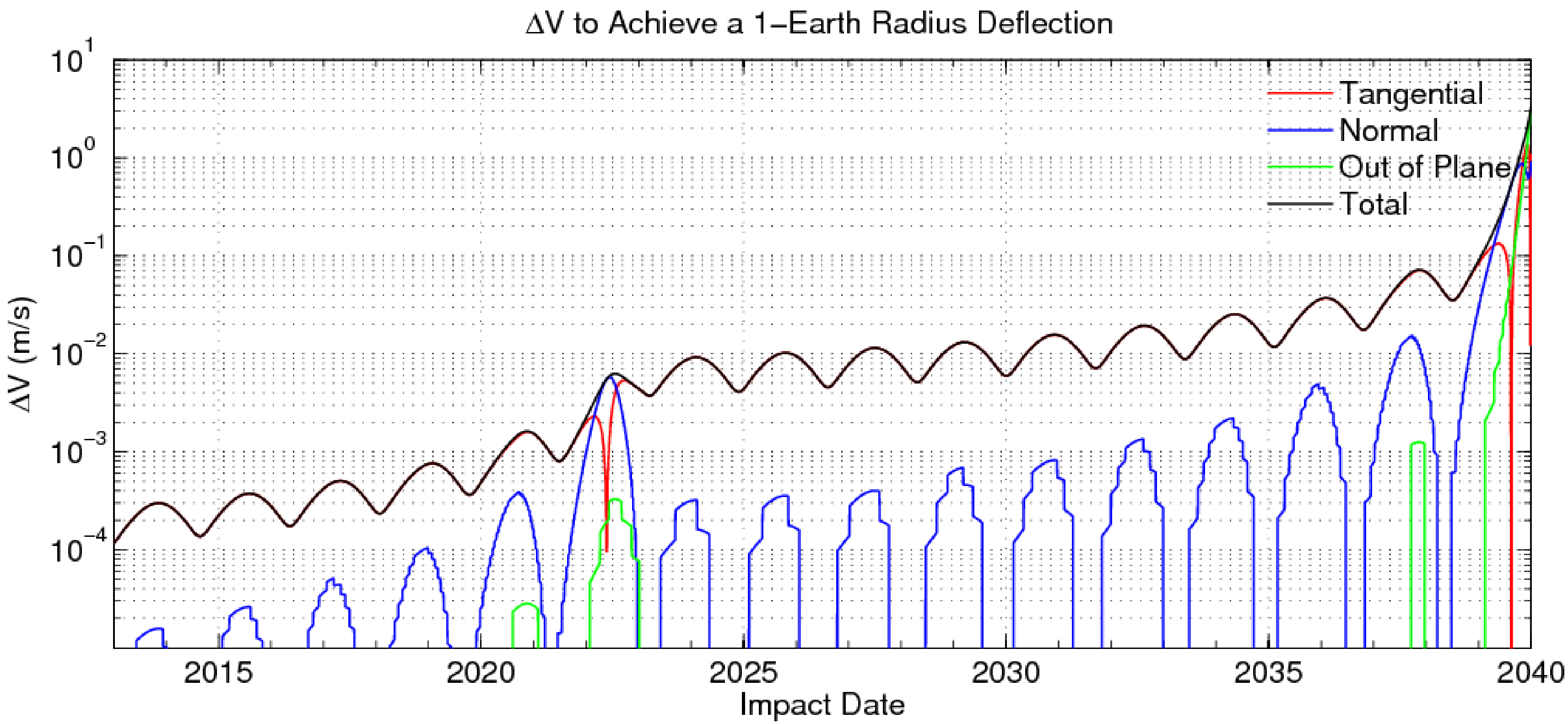
Deflection requirements

NEODET Tool (2)

- Two types of interaction are supported:
  - Impulsive: introduction of an instantaneous Δv at t=tb
  - Continuous: force model (e.g. constant thrust) applied from t=tb for a given length of time Tp
- Direct problem (any interaction type)
  - I/O: interaction level (Δv or Tp) → induced |Δb|
  - Use case: testing a particular deflection case
- Impulsive hybrid problem
  - I/O: attainable |Δv| → maximum achievable |Δb|, Δv direction
  - Use case: finding the best date for a nuclear bomb with a given yield
- Impulsive inverse problem
  - I/O: desired |Δb| → optimal Δv with minimum |Δv|
  - Use case: finding the best date and orientation for a kinetic impactor
- Continuous inverse problem
  - I/O: desired |Δb| and the force model → required application time
  - Use case: dimensioning the length of a slow-push deflection mission

NEODET Tool (3)

- Typical results



Δv required to deflect 2011 AG5 versus t_b for an impulsive inverse case

RIMISET Tool (1)

- A modular repository of mitigation mission simulators
  - Based on NEODET results, tests a set of deflection methods for each date of arrival to the NEO
  - Each method simulates a deflection mission launched from Earth; requires information on the Earth-NEO transfers
  - Reports a series of figures of merit for the user to compare
- No orbital propagation performed. Results in terms of:
  - Obtained Δv or maximum thrust time (direct problems)
  - Mission Earth escape mass for the given launcher capabilities (inverse problems)

Deflection data
Transfers to NEO
Chosen methods

RIMISET

Global FoM
Method-specific
information...

RIMISET Tool (2)

- Mitigation methods form the core of RIMISET
  - Impulsive deflection and continuous deflection methods included
  - Modular architecture which simplifies adding new methods
- Input data for the tool contains:
  - NEODET deflection files, the result of an inverse problem
  - Transfer information files (computed with transfer optimisation tools)
  - Any number of operating phase engine definitions
  - Information on the physical characteristics of the NEO
  - One or more mitigation methods, with their specific data
- Mitigation methods included:
  - Kinetic impactor
  - Nuclear explosions (surface and stand-off)
  - Gravity tractor (inertial hovering and orbiting)
  - Ion-beam shepherd

RIMISET Tool (3)

Kinetic impactor

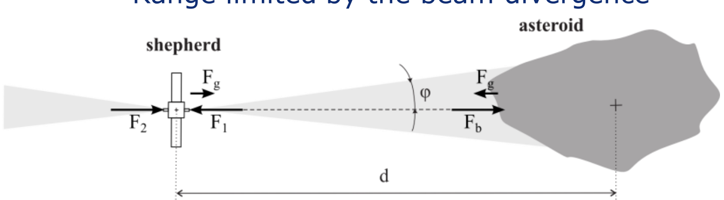
- Impulsive method
- Experimental model by Housen, Holsapple et al.
- The value of Δv depends on the NEO material properties
  - Large uncertainty depending on porosity, material strength, surface gravity, NEO shape, etc.

Nuclear explosion

- Impulsive method
- Experimental model by Solem, for both surface and stand-off blasts with different constants
- The obtained Δv depends on the NEO surface material
  - Same uncertainty problems; chemical and optical information required.

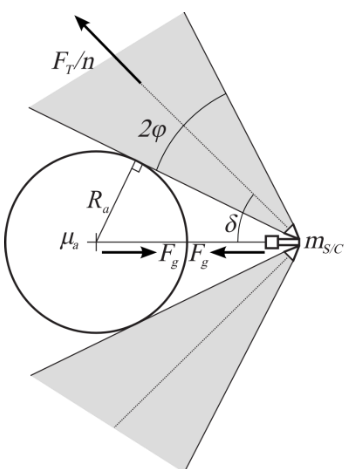
Ion beam shepherd

- Continuous method
- Model by Bombardelli and Peláez
- Requires two balanced thrusters
  - Maximum propulsive efficiency is only 50%
- S/C may be further off the NEO
  - Far enough that mutual gravity is negligible
  - Range limited by the beam divergence



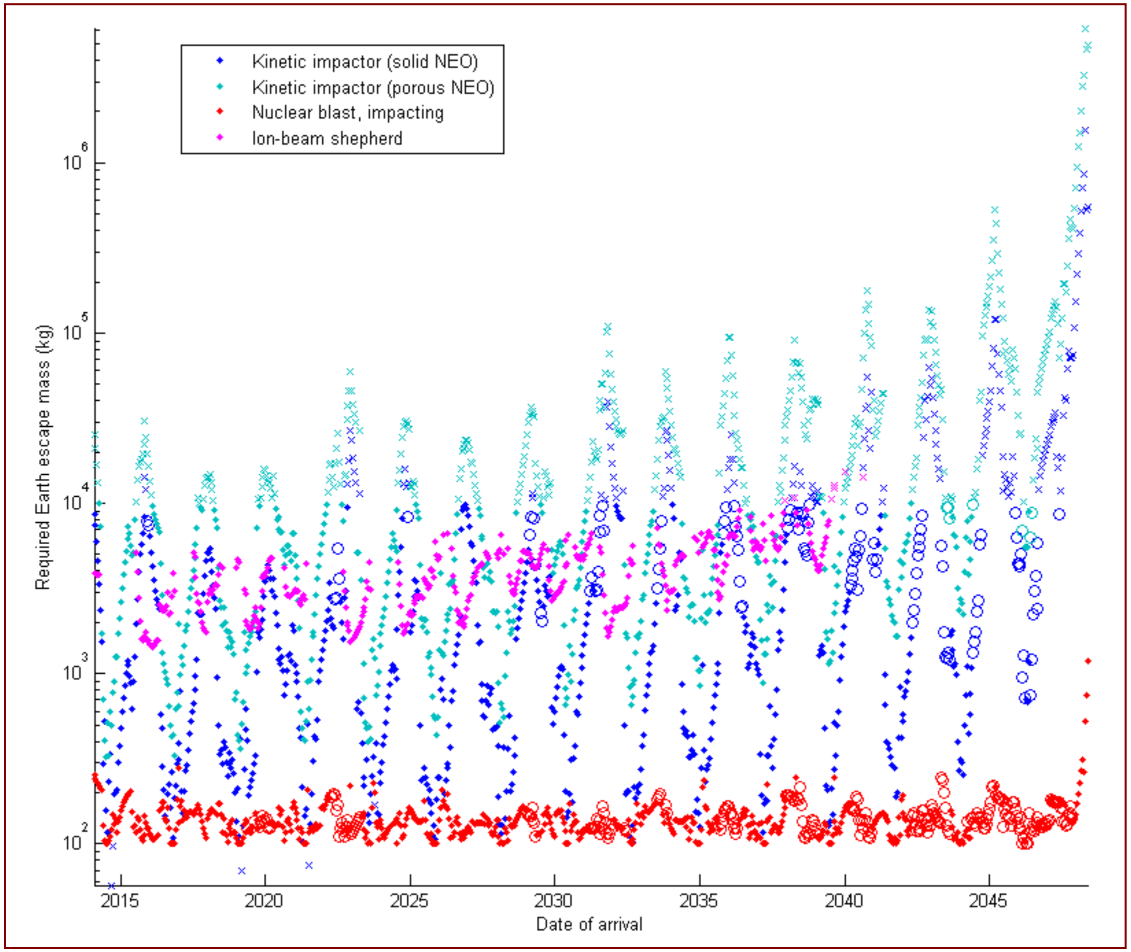
Gravity tractor

- Continuous method
- Two models implemented
  - Hovering GT: aligned with the NEO
  - Orbiting GT: in a displaced orbit around it
- Large S/C mass needed for a meaningful force
- Requires close proximity: complex control requirements



RIMISET Tool (4)

- Typical results



Left: comparison of several deflection strategies for 2007 VK184

Conclusions

- A suite of three software tools has been developed in the frame of NEOShield FP7 project for:
  - NEO risk assessment on Earth
  - NEO deflection delta-V requirements
  - NEO deflection mission specification
- The tools are executed in chain to produce a S/C dimensioning compatible with the deflection needs
- Validation cases have been executed over 2011 AG5 case and 2007 VK 184
- The suite was successfully used in last year's Planetary Defense Conference for the tabletop exercise over a fictitious threat
- The suite can be applied recurrently to any risky NEO identified in the future

Thank you for your attention!

NEO Threat Mitigation Software Tools

juan-luis.cano@deimos-space.com

www.elecnor-deimos.com
www.deimos-space.com